

ORGANIC CARBON IN WATER—LEVELS IN THE KANPUR WATER WORKS AND REMOVAL BY COAGULATION

by

JAMEEL AHMAD KHAN

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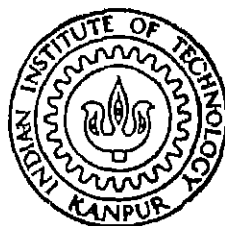
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ORGANIC CARBON IN WATER—LEVELS IN THE KANPUR WATER WORKS AND REMOVAL BY COAGULATION

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In Partial Fulfilment of the Requirements
for the Degree of

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by

JAMEEL AHMAD KHAN

to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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CERTIFICATE

Certified that the work presented in this thesis entitled "Organic Carbon in Water-Levels in the Kanpur Water Works and Removal by Coagulation" by Jameel Ahmad Khan has been carried out under my supervision and has not been submitted elsewhere for a degree.

May, 1988


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ABSTRACT

The present study is the first of its kind in India in which levels of total organic carbon (TOC) at various stages of treatment in a water treatment plant were estimated. In the Kanpur Water Works, raw water (river Ganga) TOC level showed seasonal variation in the range 1.38-6.36 mg/L, the peak (5.91-6.36 mg/L) being during February-June. TOC levels in the treatment trains were significantly higher in the summer (2.74-5.45 mg/L) compared to those in the postmonsoon period (1.95-2.51 mg/L) of 1987. According to published information on TOC levels for trihalomethane formation and water quality deterioration in the distribution system, both potentials existed in the Kanpur Water Works. A laboratory study on removal of total organic carbon from the raw water (river Ganga) by alum coagulation indicated that no significant improvement in TOC removal could be attained by modifying the present coagulation practice; however, increase in plant alum dose (25-35 percent) may prove beneficial in lowering the TOC levels of water.

1. INTRODUCTION

Organic matter in surface waters is almost as ubiquitous as water itself though its levels vary depending upon the source of the water. Its contribution to plant growth by supplying nutrients and other trace elements has been recognized and encouraged. On the other hand, presence of organic matter in drinking water has been viewed with growing concern. It is not that suddenly organic matter has become dangerous. Development of sophisticated techniques in analytical chemistry and their application to analyses of water have led to isolation of few thousand organic compounds in natural waters. These compounds are found in the $\mu\text{g/L}$ level and many have resulted from human activities. A large number of these compounds are carcinogenic, mutagenic, or carcinogen promoters (Kraybill, 1981). Besides this, there are other serious problems which stem from the presence of organic matter in drinking water. Eversince the recognition of the presence of trihalomethanes in drinking water in 1974 (Bellar et al., 1974), concern regarding their health effects is growing and is reflected by a vast body of literature pertaining to removal of trihalomethanes and their precursors (Arguello et al., 1979; Glaze and Rawley, 1979; Babcock and Singer, 1979; Oliver and Lawrence, 1979; and Norman et al., 1980). Also, organic matter leads to taste and odour problems, colour, increase in coagulant dose, depletion of chlorine and its consequences (Rosenzweig et al., 1986), deterioration of water quality in the distribution system

(O'Connor et al., 1975), reduction in water carrying capacity of pipes (Krishnamoorthy et al., 1976), fouling of ion exchange resins and membranes, and reduction in the service time of activated carbon beds.

In India, studies pertaining to levels of organic matter in drinking water are almost non existent. Thakkar et al. (1984), conducted the only study to find the reaction products of chlorine with organic matter (chloroform) in few water treatment plants, including the Kanpur Water Works. At the time of their study, the chloroform levels were found to be within the permissible limit of 30 µg/L as recommended in the Guidelines for Drinking-Water Quality (1984). While the problem of water quality deterioration and reduction in water carrying capacity were attributed to organic matter in water in several previous studies (Gadkari and Krishnamoorthi, 1979 and Krishnamoorthy et al., 1970), no efforts were directed towards estimating the amount of organic matter in water or its removal.

The present study is the first of its kind in India in which levels of organic matter (organic carbon) at various stages of treatment in a water treatment plant were estimated. The study also included laboratory evaluation of organic carbon removal by coagulation with a view to suggest possible modification, if found appropriate.

2. ORGANIC MATTER IN WATER AND ITS REMOVAL

2.1 Nature and Source of Organic Matter in Surface Waters

Organic matter in most surface waters may originate from two sources, viz., anthropogenic and natural. Anthropogenic source of organic matter is chiefly a result of discharge of municipal and industrial wastes, runoff from agricultural fields and leachates from landfills. It is this source which adds numerous toxic and highly hazardous chemical components to the water bodies. The organic matter added by man-made pollution has characteristics different from those occurring naturally. It is found that most of the naturally occurring hydrocarbons in water contain odd number of carbon atoms, while hydrocarbons added by man contain even number of carbon atoms (Matsumota and Hanya, 1981). A large fraction of the anthropogenic organic matter disappears as a result of biodegradation, but still a significant fraction may persist. The proportions of organic matter contributed by the two sources vary, but will depend upon the extent of contribution. In certain rivers, the organic content continues to increase along its course mainly due to pollution, indicating organic matter contributed by pollution being far greater than that from natural sources.

The naturally occurring organic matter in water consists of a mixture of plant and animal products in various stages of decomposition, of substances synthesized biologically and/or chemically from the breakdown products, and of microorganisms and small animals and their decomposing remains. Most of the

natural organic matter in water has its origin in the soil which is picked up by the overflowing or percolating water.

The bulk of the organic matter in most waters consists of humic substances. These are amorphous brown or black, hydrophilic, acidic, polydisperse substances of molecular weight ranging from several hundreds to tens of thousands. The humic fraction is further subdivided into humic acid, fulvic acid and humatomeLANIC acid depending upon their solubility under different pH conditions. Some of the important characteristics of humic substances are resistance to microbial degradation, ability to form stable water-soluble and water-insoluble salts and complexes, and to interact with metal ions, hydrous oxides, clay minerals and organic chemicals which may be toxic pollutants.

A smaller fraction of organic matter consists of non-humic substances which includes compounds that exhibit still recognizable chemical characteristics. These compounds, in general, have relatively short survival rates and are easily attacked by microorganisms. Carbohydrates, proteins, peptides, amino acids, fats, waxes, resins, pigments and other low molecular-weight organic substances constitute the non-humic fraction of the organic matter.

2.2 Health Effects

Organic matter may not be harmful by itself but its association with toxic chemicals, heavy metals and the reaction byproducts are the most feared health hazards. Humic substances, due to their excellent complexing ability, can transport heavy

metals in significant amounts. Under favourable conditions, they may complex heavy metals in almost equal quantity by weight as the humic material itself (Schnitzer and Skinner, 1963). Organic matter is associated with a number of toxic organic and inorganic compounds in soil many of which may finally find their way into drinking water (Morris et al., 1982). A large number of organic chemicals found in water are known to be toxic or carcinogenic and are harmful even at low levels at which they are present in water. Bacterial cultures in such water concentrations (obtained by reverse osmosis) were found to show mutagenic activity (Kraybill, 1981). Organic matter is also the limiting source of organic carbon for a vast number of microorganisms found in the water distribution system. O'Connor et al. (1975) recommend water COD of 10 mg/L or less to overcome the problem of biological growth in the distribution system. Reaction products of organic matter, particularly the trihalomethanes, are suspected of causing bladder cancer (Kraybill, 1981). Recognizing the organic matter as a precursor of trihalomethane formation, many workers have suggested that the total organic carbon (TOC) content of water be brought down to a level of 1 mg/L or less to restrict trihalomethane formation to 100 µg/L. Organic matter also causes depletion of chlorine and is thereby responsible for lowering the residual protection of water supplies.

2.3 Levels of Organic Matter in Surface Waters

Levels of organic matter present in most natural waters vary and depend upon the nature of surface and subsurface soil layers. Humic materials are leached from decaying plant materials or humus on the land surface and transported by surface and

subsurface waters in soluble or colloiddally dispersed form. Natural organic matter shows marked seasonal variations. The second source of organic matter is of more recent origin and is attributed to man-made pollution. Discharge of vast quantities of wastes into surface waters has led to an increase in the organic matter level of many receiving waters. The river Rhine is an example of such pollution. In the upper tributaries, TOC level was found to be 1.3 mg/L and as the river passes through Switzerland, France and Germany, this level increased to 8 mg/L at Cologne and finally reached 10-12 mg/L at Rotterdam. Typical organic carbon levels in some natural waters are shown in Table 1.

2.4 Organic Matter - Clay Interactions in Water

Organic matter in most natural waters is generally present along with a number of substances like clay and other inorganic materials. While studying the removal of organic matter from water, it is important to consider its interaction with clay. Dispersed clay minerals in natural waters adsorb organic substances. The extent of adsorption depends upon the type of clay, cationic form of the clay and the solution pH. The complexity of organic matter in water poses difficulty in explaining the mechanisms by which they interact with clay. Some of the mechanisms responsible for organic matter-clay interactions are listed below.

a. Anion-Exchange Reactions. Reversible adsorption of organic matter occurs by the formation of polyhydroxy complexes with iron and aluminium at the clay surfaces. At pH less than 8,

Table 1. Organic Carbon Levels in Natural Waters.

Location	Total Organic Carbon (mg/l)
<u>U.S.A.</u>	
Von Norman Reservoir, Los Angeles Dept. of Water and Power	1.2
San Andreas Reservoir, San Francisco Water Dept.	1.3
Colorado River Aqueduct, San Diego Water and Utility Dept.	2.9
Contra Costa Canal, Contra Costa Country Water Dept.	3.5
Mississippi River, St. Paul, Minn.	7.9
James River, Huron, S.D.	19.2
<u>Europe</u>	
Lake Zurich	1.2
Lake Constance	1.3
Rhine River, Basel	3.0
Neckar River, Stuttgart	6.0
Rhine River, Cologne	8.0
Rhine River, Rotterdam	10 - 12

Adapted from Kavanaugh (1978).

positive sites normally exist on aluminium and iron hydroxides and the organic anions can be associated with these charges by coulombic attraction. The organic anion can be displaced by raising the pH to 8 or 9, when the positive charge of hydroxide is neutralized.

b. Ligand-Exchange Reactions. Organic anion penetrates the coordination shell of an iron or aluminium atom in the surface of the hydroxide and becomes incorporated into the hydroxy layer. This reaction is sometimes irreversible (Schnitzer and Khan, 1972).

c. Hydrogen Bonding. This is an important bonding process, particularly in large molecules or polymers where additive bonds of this type may produce a relatively stable complex.

Besides the above mentioned mechanisms, adsorption of organic matter may occur in the interlamellar spaces of the clay particles. At any time, one or more mechanisms may be responsible for organic matter-clay interactions.

2.5 Organic Matter-Metal Coagulant Interaction in Water

The literature information on organic matter-metal coagulant interaction in water is mainly restricted to interactions between humic substances in water and metal coagulants. The information originated primarily from studies employing humic substances (humic and fulvic acid) extracted from soil, peat, decaying vegetation and river water. Reviewing the past work of well-known researchers in the area, coagulation of humic substances by metal coagulants has been summarized as follows (Committee Report, 1979).

Coagulation of humic substances with metal coagulants can be accomplished through two mechanisms, e.g., destabilization-charge neutralization or precipitation. Both may contribute to coagulation simultaneously. Considering alum as the coagulant for the purposes of discussion, destabilization may be accomplished by charge neutralization resulting from specific chemical interaction between the positively charged aluminium species and the negatively charged groups on the humic colloids. The fixation of multivalent cations onto ionized groups on hydrophilic colloids may be caused by electrostatic or chemical interaction, reducing the charge of the particles and altering their solubility. Destabilization by this mechanism would be accomplished over a narrow pH range (pH 4-6), and a stoichiometric relationship between the raw water humic concentration and the optimum coagulant dose would be observed. In the second mechanism, humic substances can form water-soluble and water-insoluble complexes with metal ions. As the alum dosage is increased, formation of metal hydroxide precipitate occurs during which incorporation of humic material within the aluminium hydroxide floc or coprecipitation as aluminium humate may occur.

Dissolved organic compounds are removed during coagulation primarily by sorption onto metal hydroxide floc based upon several mechanisms of adsorption, such as physical sorption, ion exchange and surface complexation (Jekel, 1986).

2.6 Removal of Organic Matter During Water Treatment

Conventional water treatment plants employing, coagulation, sedimentation, filtration and disinfection are considered to

provide turbidity and pathogen free drinking water. The coagulation step, along with removal of turbidity is partially successful in removing organic matter. A study by Steven and Symons (1977) indicated that maximum removal occurred after coagulation and settling, and also significant amount of organic matter removal was observed in the filters. Wide range of organic matter removal has been observed in conventional water treatment plants. Lange and Kawczynski (1978) observed 60 percent reduction in TOC during treatment of water obtained from the Sacramento-San Joaquin delta. Removals in the range 20-40 percent were observed in treated waters from the Rhine and Alpine lakes, (Kavanaugh, 1978). The Colorado river water from lake Mathews did not show any removal of organic matter after treatment (Cohen et al., 1978).

In laboratory studies on alum coagulation, Chadik and Amy (1983) observed 31-59 percent removal of TOC from several natural waters at ambient pH conditions with alum dose in the range 2.5-30 mg Al/L. Semmens and Field (1980) reported 36-53 percent TOC removal in laboratory coagulation of Mississippi river water using alum dosage in the range 25-100 mg/L at pH 5.0, followed by filtration through Whatman No. 1 filter paper.

In order to achieve a minimum acceptable level of organic matter in the treated water, activated carbon adsorption is usually incorporated in the treatment train. In view of high cost of activated carbon, the developing countries, however, have to rely upon the removal of organic matter by the conventional treatment units.

3. SCOPE OF THE STUDY

Presence of organic matter and their reaction products with chlorine (trihalomethanes) in drinking water have been a growing concern for environmental engineers because of their possible adverse health effects. Many plant-scale and laboratory studies pertaining to trihalomethane formation and removal of trihalomethanes as well as their precursors have been reported in the literature from the developed countries. Levels of organic matter in natural waters and in water treatment plants have also been reported. In the Indian scene, such information is not available. Only one study on levels of chloroform in few water treatment plants in India has been reported (Thakkar et al., 1984). It appears appropriate to conduct studies on the levels of organic matter (organic carbon) in Indian water treatment plants. The present study was undertaken in two phases:

1. Estimation of organic carbon levels in the treatment trains at the Kanpur Water Works.
2. Laboratory coagulation study on removal of organic carbon from the Kanpur Water Works raw water with a view to suggest possible modification, if found appropriate.

4. ORGANIC CARBON LEVELS IN THE KANPUR WATER WORKS

4.1 Kanpur Water Works

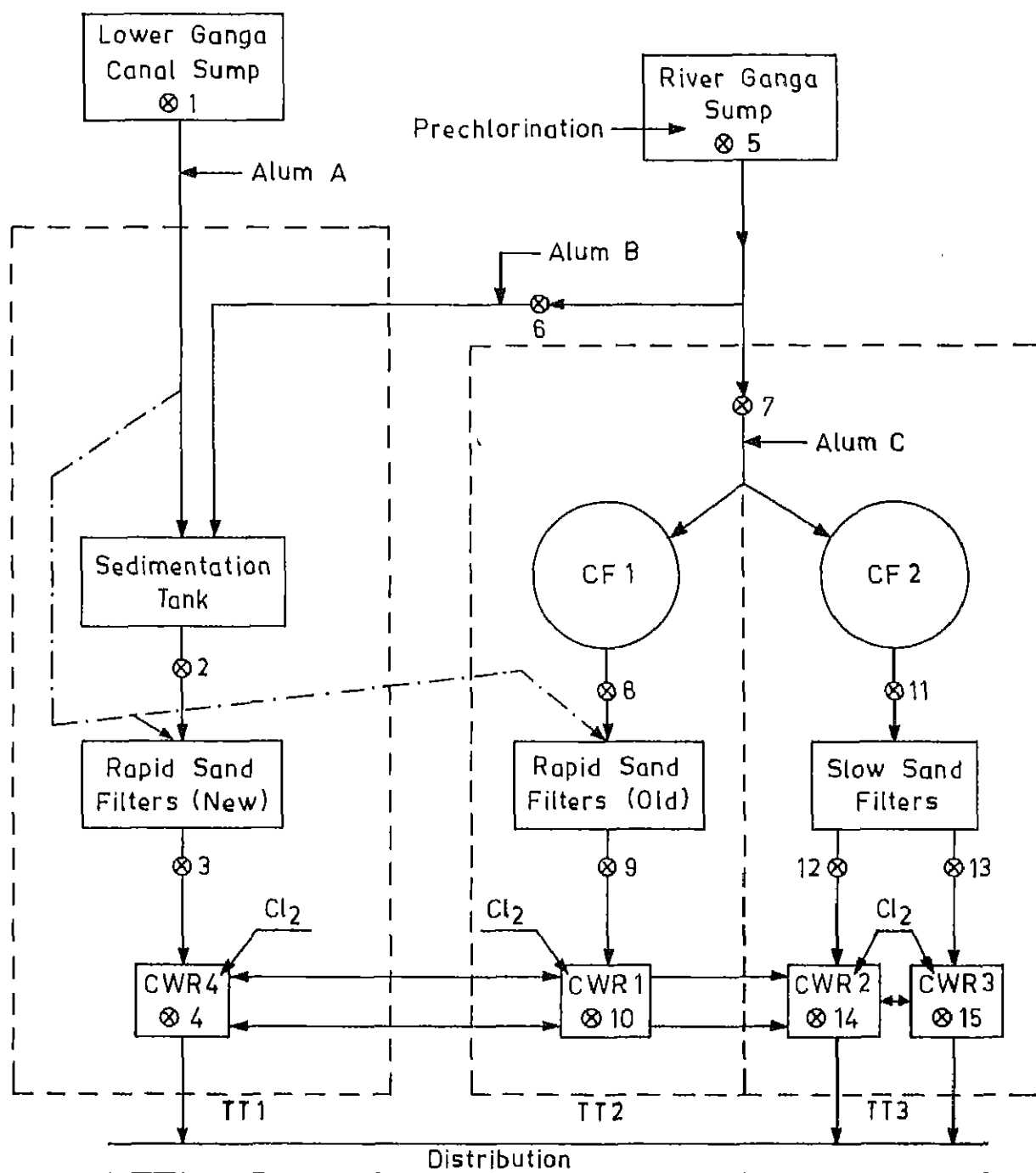
The Kanpur Water Works, located at Benajhabar, Kanpur, supplies approximately 255 MLD (million litres per day) drinking water to a population of about 2 million. It draws its supplies from two main sources, viz., the river Ganga and the Lower Ganga Canal. By and large, the river Ganga remains the main source which supplies about 200 MLD. The Lower Ganga Canal augments the raw water supply by contributing about 45 MLD. Rest of the demand is met by tapping the ground water.

The Kanpur Water Works employs the conventional method of water treatment, e.g., sedimentation, coagulation-sedimentation/clariflocculation, slow/rapid sand filtration and chlorination (Figure 1). Alum dosing is done by placing alum bricks in submerged cribs with hydraulic jumps for flash mixing.

4.2 Sampling

All glassware used for collecting samples for estimation of organic carbon were cleaned using chromic acid followed by several washings with tap water and final rinsing with triple distilled water. The rubber lined screw caps of 60 mL sampling tubes were washed with distilled water followed by rinsing with triple distilled water.

The sampling points are shown in Figure 1. The locations were so chosen as to assess the levels of TOC in the treatment trains. Accordingly, 15 sampling points were selected. At each point, sampling bottle and sampling tubes were rinsed



CF : Clariflocculator ; CWR : Clear Water Reservoir ; TT : Treatment Train
 ⊗ Sampling Point ; - - - - Bypass (October, 1987)

Fig. 1. Schematic Layout of the Kanpur Water Works Showing the Sampling Points.

thrice with the sample water before collecting samples in triplicate. Samples were acidified ($\text{pH} < 2$) using hydrochloric acid and refrigerated (Standard Methods, 1985). Samples were not iced while transporting to the Environmental Engineering Laboratory, I.I.T., Kanpur. On arrival, the samples were immediately refrigerated. Samples were collected in summer (June) and in the postmonsoon period (October) during 9:30-11:30 A.M.

A separate sampling programme was followed to monitor variation in organic carbon level during the day (8:30 A.M. to 8:30 P.M.) at five selected sampling points, viz., river Ganga sump (Q 5), slow sand filter effluent (Q 13), CWR3 (Q 15), rapid sand filter effluent (Q 3), and CWR4 (Q 4). In this programme, the number of sampling points was reduced to facilitate collection as well as analysis of the samples.

4.3 Analysis of Samples

Samples were analyzed for total organic carbon (TOC) using an organic carbon analyzer (Photochem Organic Carbon Analyzer, Saybron Corporation, Boston, Massachusetts, U.S.A.). The analyzer functions on the principle of measuring change in resistivity produced by carbon dioxide evolved from organic carbon by ultraviolet oxidation. Due to occasional lack of reproducibility, each sample was analysed thrice. Unless mentioned otherwise, the mean of three analyses is reported as TOC (mg/L).

4.4 Organic Carbon Levels

Table 2 shows the TOC levels at various sampling points in the summer (June) and in the postmonsoon period (October) of

Table 2. Organic Carbon Levels at Various Sampling Points in the Kanpur Water Works.

Sampling Point and Location	Total Organic Carbon (mg/L)									
	June 17, 1987					October 13, 1987				
	Sample 1	Sample 2	Sample 3	Mean±S.D.	Sample 1	Sample 2	Sample 3	Mean±S.D.	Sample 1	Sample 2
1. Lower Ganga Canal Sump	3.12	2.99	2.81	2.97±0.16	1.80	1.78	1.75	1.73±0.03		
2. After Sedimentation	3.43	3.14	3.12	3.23±0.17	*		*	-		
3. Rapid Sand Filter (New) Effluent	3.27	2.62	2.34	2.74±0.48	1.35	1.34	1.30	1.33±0.03		
4. Clear Water Reservoir (CWR4)	3.95	3.87	3.71	3.84±0.12	1.90	1.76	1.74	1.80±0.09		
5. River Ganga Sump	5.12	4.56	4.35	4.66±0.40	2.58	2.56	2.52	2.55±0.03		
6. Before Alum Dosing (Alum B)	4.46	3.79	3.68	3.96±0.43	*	*	*	-		
7. Before Alum Dosing (Alum C)	6.74	6.16	6.16	6.36±0.33	2.82	2.77	2.61	2.73±0.11		
8. After Clariflocculator (CF1)	4.42	4.34	4.27	4.34±0.06	*	*	*	-		
9. Rapid Sand Filter (Old) Effluent	4.90	3.23	-	4.07±0.08	2.80	2.71	2.66	2.72±0.07		
10. Clear Water Reservoir (CWR1)	3.21	2.86	2.64	2.90±0.29	2.22	2.14	2.09	2.15±0.06		
1. After Clariflocculator (CF2)	5.17	4.12	3.89	4.39±0.68	2.54	2.54	2.45	2.51±0.05		
2. Slow Sand Filter Effluent	4.65	4.12	3.89	4.22±0.39	2.01	1.98	1.95	1.96±0.03		
3. Slow Sand Filter Effluent	5.26	5.12	4.56	4.98±0.37	2.10	2.05	1.85	2.00±0.13		
4. Clear Water Reservoir (CWR2)	4.91	4.34	4.26	4.60±0.35	2.07	2.03	1.76	1.95±0.17		
5. Clear Water Reservoir (CWR3)	5.59	5.52	5.24	5.45±0.19	2.30	2.25	2.23	2.26±0.04		

* Sedimentation Tank and Clariflocculator (CF1) closed down for desludging. Rapid Sand Filters (New and Old) were operated in direct filtration mode with the Lower Ganga Canal water (Figure 1).

1987. In general, raw water TOC levels were higher in the summer (Lower Ganga Canal 2.97 mg/L; River Ganga 3.79-6.36 mg/L) than in the postmonsoon period (Lower Ganga Canal 1.78 mg/L; River Ganga 2.55-2.75 mg/L). Consequently, the TOC levels were correspondingly higher in the treatment trains in the summer (2.74-5.45 mg/L) than in the postmonsoon period (1.33-2.73 mg/L).

Even though the sampling schedule employed does not allow a quantitative evaluation of TOC removal by different units, levels of TOC at various stages in the three treatment trains are shown in Figures 2 and 3 so as to provide a qualitative picture of the TOC levels in the treatment trains. Sedimentation tank and clariflocculator (CF1) were closed down for desludging in October, 1987. Rapid sand filter (old and new) were operated in direct filtration mode with the Lower Ganga Canal water. In general, the TOC levels at the various stages of the treatment train did not show significant variation in the postmonsoon period whereas considerable variations were noticeable in the summer.

Figure 4 shows variation in TOC levels at five selected sampling points during 8:30 A.M.-8:30 P.M. (22 November, 1987). The extent of variation was different for all five points; raw water (River Ganga) showed major variation, the minimum and maximum being 1.58 and 3.74 mg/L, respectively. Between 8:30 A.M. and 3:30 P.M., the raw water TOC level declined almost steadily from 3.15 mg/L to 1.58 mg/L. This was followed by a steady increase in TOC level with a peak at about 6:30 P.M. and steady decline thereafter till 8:30 P.M. (1.74 mg/L). The TOC levels in slow sand filter effluent were in the range 1.5-2.91 mg/L, while rapid sand filter effluent TOC levels showed a narrow range (1.24-1.89 mg/L). High TOC levels in the reservoirs

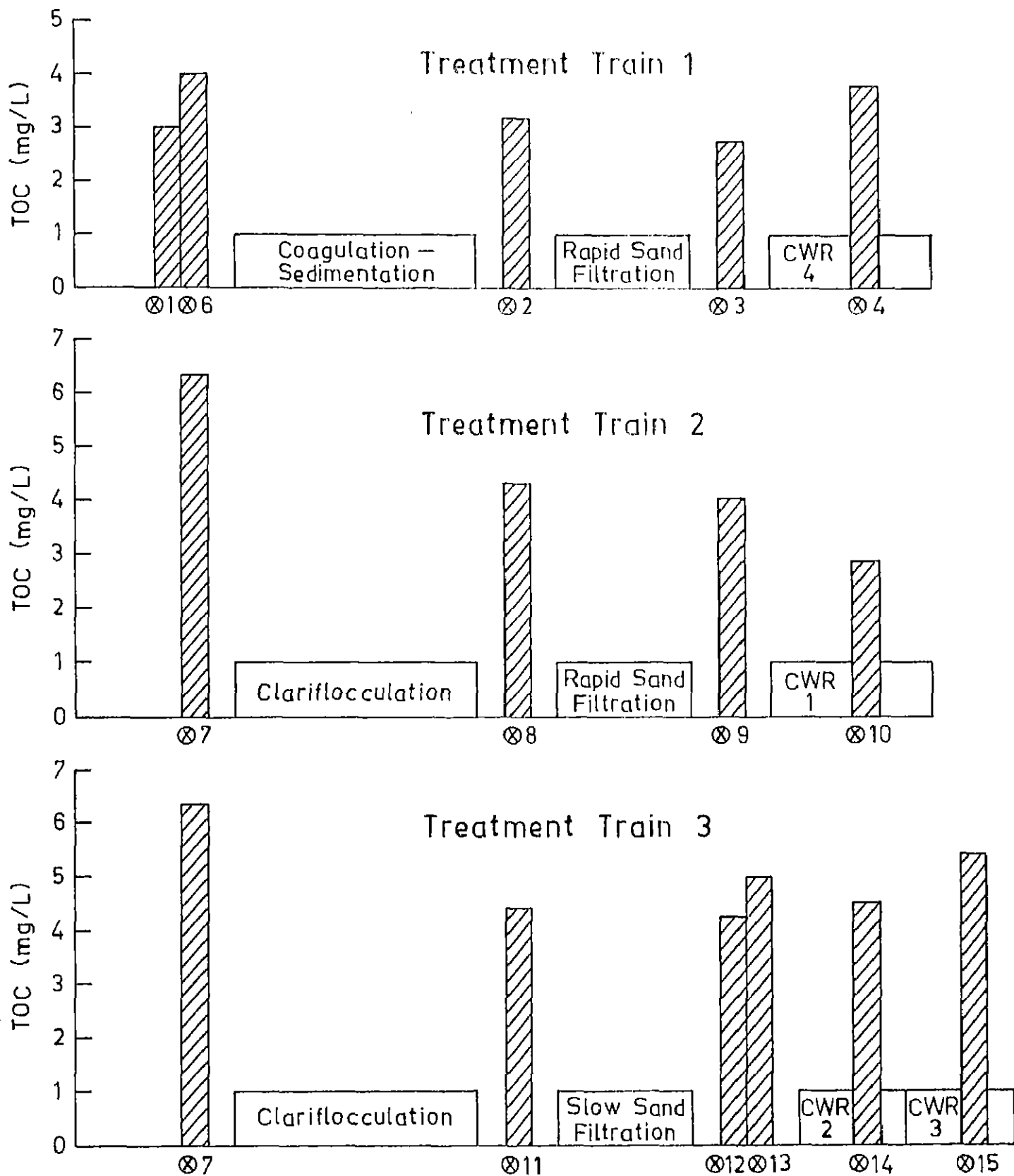


Fig. 2. Organic Carbon Levels at Various Stages of Three Treatment Trains (June, 1987).

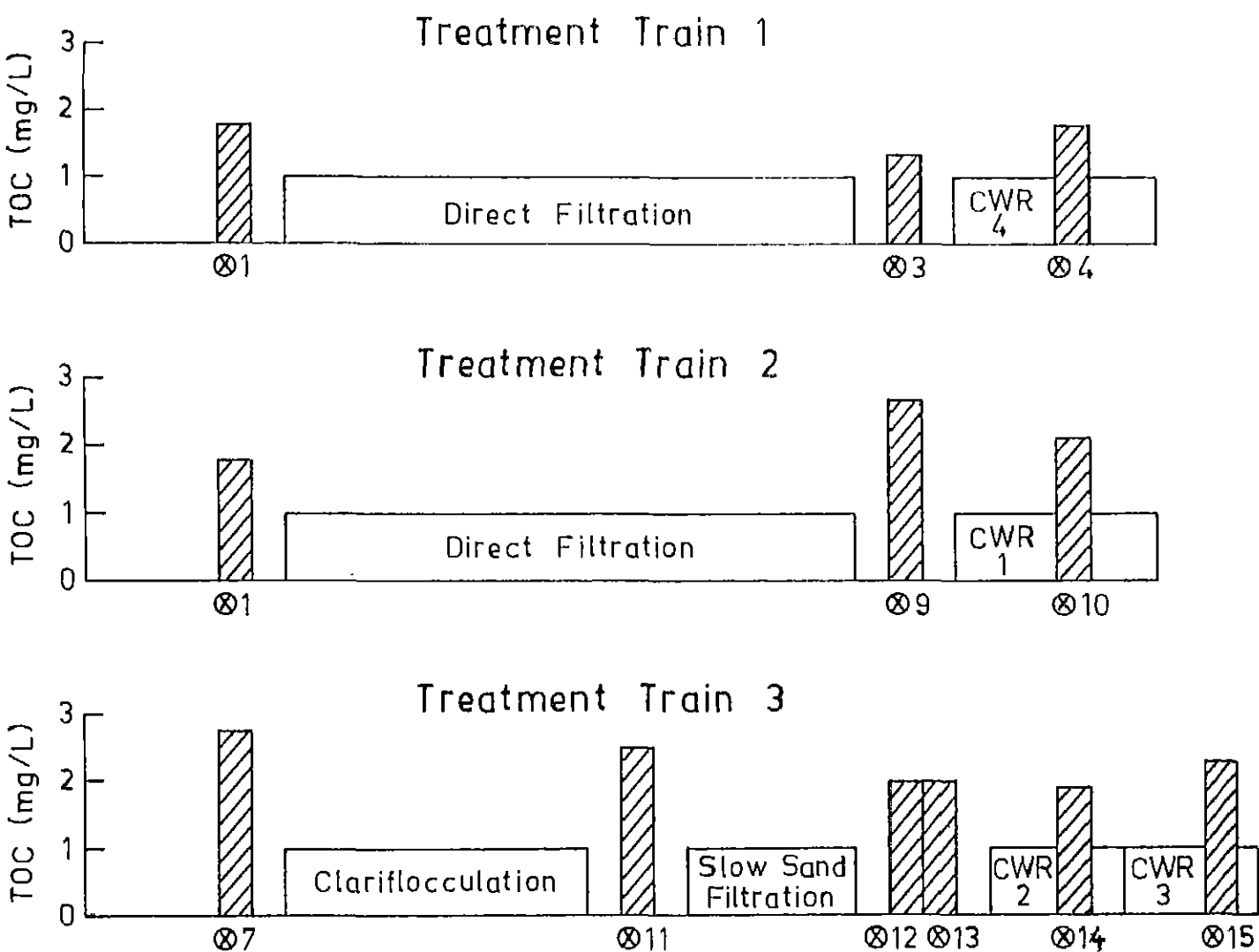


Fig. 3. Organic Carbon Levels at Various Stages of Three Treatment Trains (October, 1987).

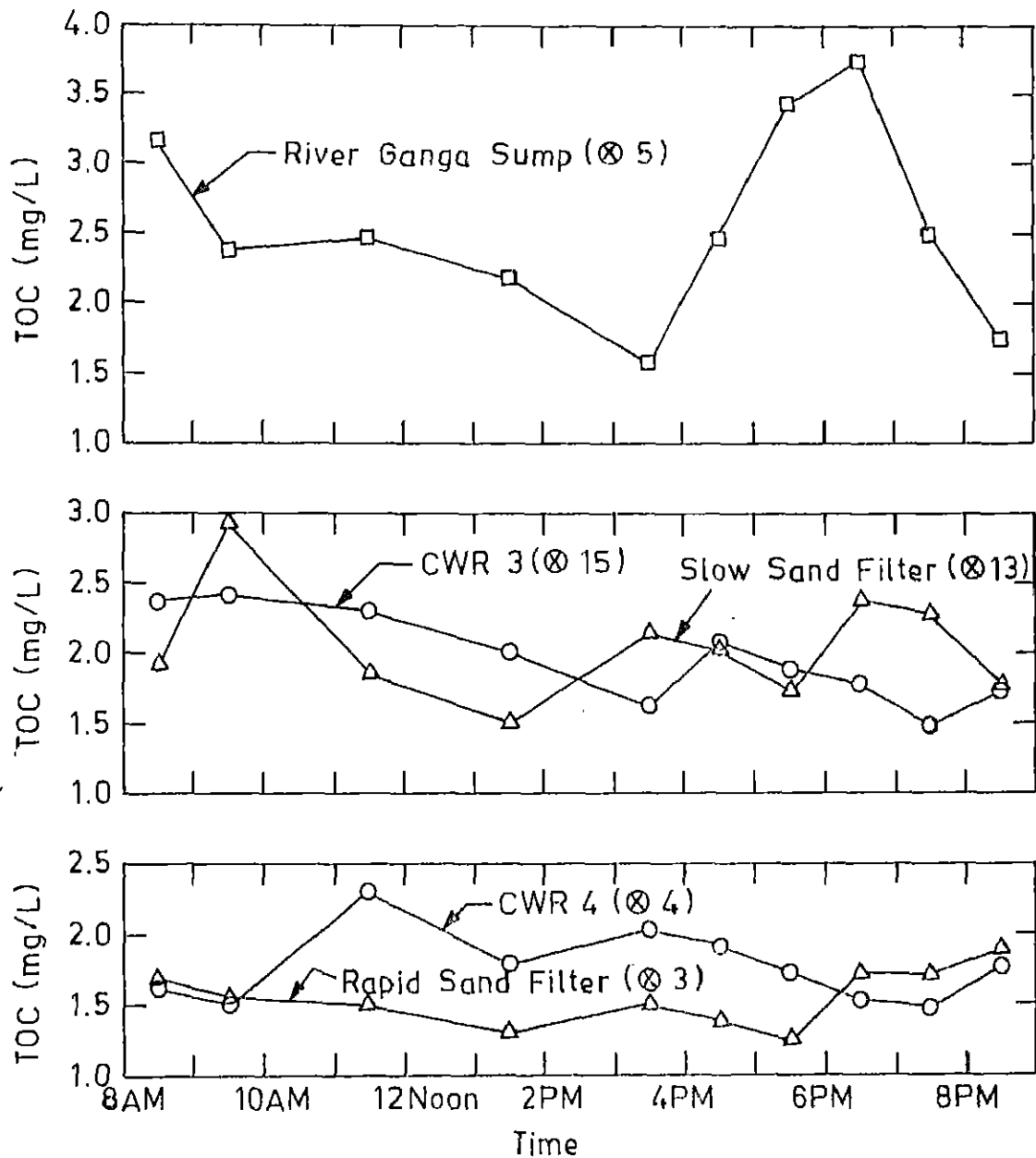


Fig. 4. Organic Carbon Levels at Five Selected Sampling Points at the Kanpur Water Works (22 November, 1987).

(CWR4 1.52-2.33 mg/L; CWR3 1.61-2.43 mg/L) could be due to reservoirs receiving water from many other filters and/or due to interconnections between the reservoirs.

Organic matter in treated water may be restricted with a view to prevent formation of trihalomethanes (THM) or deterioration of water quality in the distribution system. A number of researchers has found correlation between THM formation potential and the TOC level of water (Kavanaugh, 1978; Oliver and Lawrence, 1979; and Chadik and Amy, 1983). According to Kavanaugh (1978), 1 mg/L TOC or less is required to meet the U.S.E.P.A. standard of 100 µg/L THM in drinking water. For preventing deterioration of water quality in the distribution system, the water COD should be less than 10 mg/L (O'Connor et al., 1975), which corresponds to a TOC level of 3.75 mg/L. From these considerations, it appears that adequate potential exists for formation of THM at the Kanpur Water Works, while deterioration of water quality in the distribution system may occur during certain parts of the year. Raw water TOC levels (River Ganga Sump) during the period of this study are shown in Table 3. This may give an idea of the TOC levels of the treated water.

4.5 Summary

Based on the limited data on organic carbon levels in the Kanpur Water Works collected during the present study, some general observations are summarized. Raw water (river Ganga) TOC levels showed seasonal variation in the range 1.38-6.36

Table 3. Organic Carbon Levels of Pay Water (River Ganga Camp)
During the Study Period.

Month	Total Organic Carbon (mg/l.)
June	3.79 - 6.36
July	1.85 - 3.32
August	1.38 - 3.31
September	1.95 - 2.59
October	2.55 - 2.73
November	1.58 - 4.18
December	3.10 - 3.62
January	3.17 - 3.29
February	4.54 - 5.91

mg/L, the peak (5.91-6.36 mg/L) being during February-June. TOC levels in the treatment trains were significantly higher in summer (June) compared to those in the postmonsoon period (October). According to information available in the literature, potential for THM formation exists in the Kanpur Water Works and deterioration of water quality in the distribution system may occur during certain parts of the year (February-June).

5. COAGULATION STUDIES ON ORGANIC CARBON REMOVAL

The coagulation-sedimentation step, followed by filtration, plays the most significant role in reducing organic carbon levels during water treatment (Stevens and Symons, 1977). This is also borne out by data on TOC levels in the treatment trains at the Kanpur Water Works (Chapter 4). A laboratory study on removal of organic carbon from the Kanpur Water Works raw water by alum coagulation was undertaken with a view to suggest possible modification in the coagulation step, if found appropriate.

5.1 Materials

Raw water samples were collected from a location about 20 m upstream of sampling point 7 in the river Ganga water channel (Figure 1) and filtered through four layers of cheese cloth before use in coagulation experiments. All glassware used were cleaned using chromic acid followed by several washings with tap water and final rinsing with triple distilled water. Alum used was filter alum obtained from the Kanpur Water Works. The sample of filter alum was found to contain 6.8 percent aluminium by weight.

Haematite, used as coagulant aid, was supplied by Sandur Manganese and Iron Ore Limited, Sandur, Karnataka. A 2 g/L suspension made with a pulverised fraction passing 53 μm sieve was used in coagulation experiments. A supernatant of a 30 min settled suspension of the lower Ganga Canal sediment in the river Ganga water was used to vary the turbidity levels in coagulation experiments.

5.2 Coagulation Experiments

Batch coagulation experiments (jar tests) were conducted using a six-place multiple stirrer (Phipps and Bird Inc., Richmond, Virginia, U.S.A.). Stirrer paddles were cleaned with carbon tetrachloride to minimize possible contamination. A set procedure was followed in raising or lowering the stirrer shafts during an experiment. A background study indicated that the procedure provided freedom from organic matter contamination. In the jar test procedure, 750 ml raw water samples were rapid mixed at the rate of 100 rpm for 1 min following alum dosing slow mixed at the rate of 30 rpm for 20 min followed by 30 min settling. Supernatant samples for TOC analysis and pH and turbidity measurements were collected from the mid-depth. Samples for TOC analysis were acidified ($\text{pH} < 2$) and refrigerated. Hydrochloric acid or sodium hydroxide was used for adjustment of initial pH in the range 5-9, when requirement. Haematite, used as a coagulant aid, was added 1 min prior to alum dosing during rapid mix.

In two-stage coagulation experiments, supernatant from the first stage coagulation with minimum residual TOC was coagulated with increasing alum dosages so that the first stage dose corresponding to minimum residual TOC and the second stage dosages added up to the corresponding increasing first stage dosages.

All TOC analyses were performed in triplicate using an organic carbon analyzer (Photochem Organic Carbon Analyzer, Saybron Corporation, Boston, Massachusetts, U.S.A.) and the mean

of three analyses are reported as TOC (mg/L). Turbidity measurements were made using a turbidimeter (model 2100A, Hach Chemical Company, Loveland, Colorado, U.S.A.) and the values are presented in Nephelometric Turbidity Unit (NTU).

5.3 Results and Discussion

5.3.1 Effect of Alum Dose and Initial pH

Since both alum dose and pH play an important role in removing organic matter from water, two sets of jar tests (July and September, 1987) were conducted with alum dosages 20, 30, 40, 50 and 60 mg/L and at initial pH values 5.0, 6.0, 7.0, 8.4 (unadjusted raw water pH) and 9.0. It may be noted that during July-September the alum dose employed at the Kanpur Water Works was in the vicinity of 30 mg/L. The jar test data presented in Figures 5 and 6 show that an alum dose of 40 mg/L produced the lowest residual TOC (July 1.74 mg/L; September 1.52 mg/L) at unadjusted raw water pH and higher alum dosages did not have any beneficial effect. In general, higher TOC removals were observed at pH values below the unadjusted raw water pH and increasing the pH was less effective in reducing TOC levels.

In order to obtain TOC levels comparable to that at lower pH values, higher alum dose (40 mg/L against 30 mg/L) was necessary at unadjusted raw water pH. Similar results were observed by Edzwald (1978) who found that much higher dosages were needed for removal of organics at pH values higher than 6. Based on these observations and considering the cost of pH adjustment, increase in the plant alum dose would be beneficial in terms of residual TOC level.

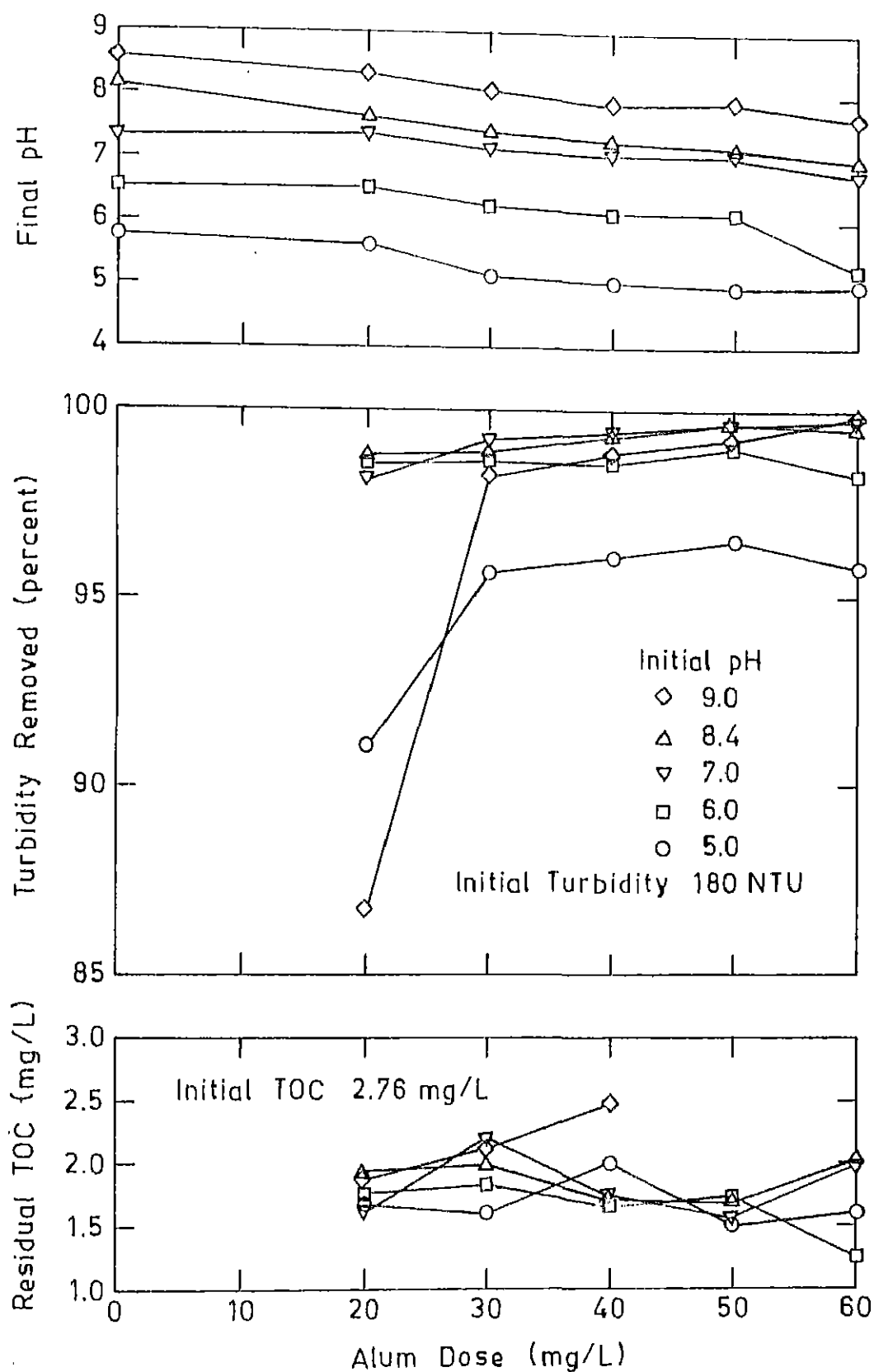


Fig. 5. Residual TOC and Turbidity Removal by Alum Coagulation at Various Initial pH Values (July, 1987).

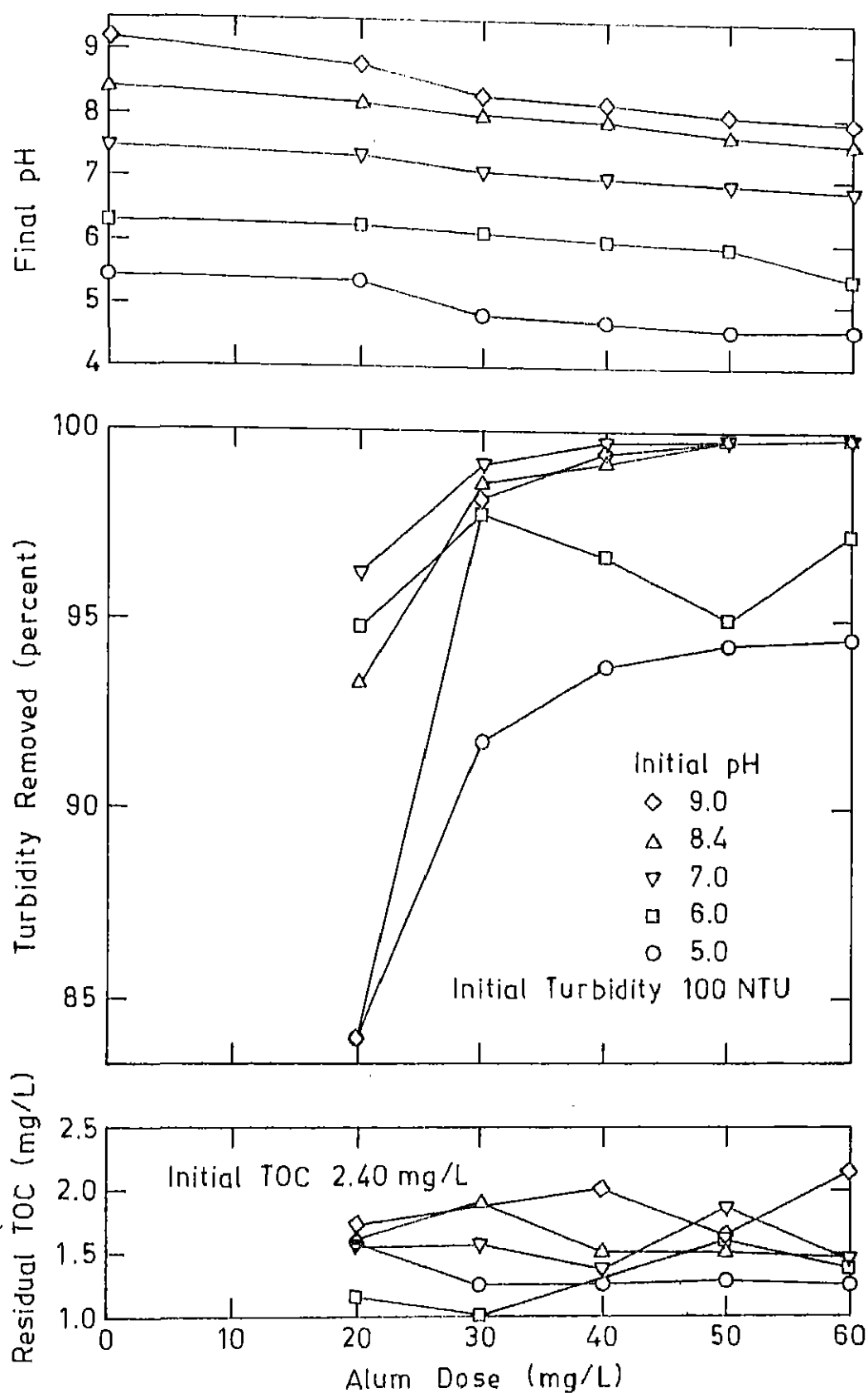


Fig. 6. Residual TOC and Turbidity Removal by Alum Coagulation at Various Initial pH Values (September, 1987).

5.3.2 Haematite as a Coagulant Aid

Jar tests were conducted to assess the feasibility of using haematite as a coagulant aid, in conjunction with alum in reducing residual TOC level. It was thought that organic matter in water would sorb on to haematite particles and this would aid in its removal by alum coagulation; additionally, haematite particles would provide nucleation sites for floc growth. During the test period (November, 1987) the plant alum dose was 15 mg/l and this was employed with varying haematite dosages (0-60 mg/l) as coagulant aid. However, residual TOC values following alum coagulation with haematite as coagulant aid (Figure 7) showed only marginal improvement in TOC levels. Haematite did not appear to be a promising coagulant aid.

5.3.3 Effect of Initial Turbidity

Jar tests conducted with high turbidity (100-180 NTU) water samples (July-September) showed rapid floc formation with good settling characteristics, whereas tests with low turbidity (7.5 NTU) water samples (December-January) showed delayed floc formation with poor settling characteristics. In general, TOC removals were also relatively poor with low turbidity waters when plant alum dosages were employed in jar tests. In order to assess possible beneficial effect of increasing the initial turbidity of low turbidity raw water, jar tests were conducted with increased initial turbidity (25, 50 and 100 NTU) using the Lower Ganga Canal sediments. It was thought that organic matter-clay interaction and additional nucleation sites for floc growth would enhance TOC removal. According to the data presented in

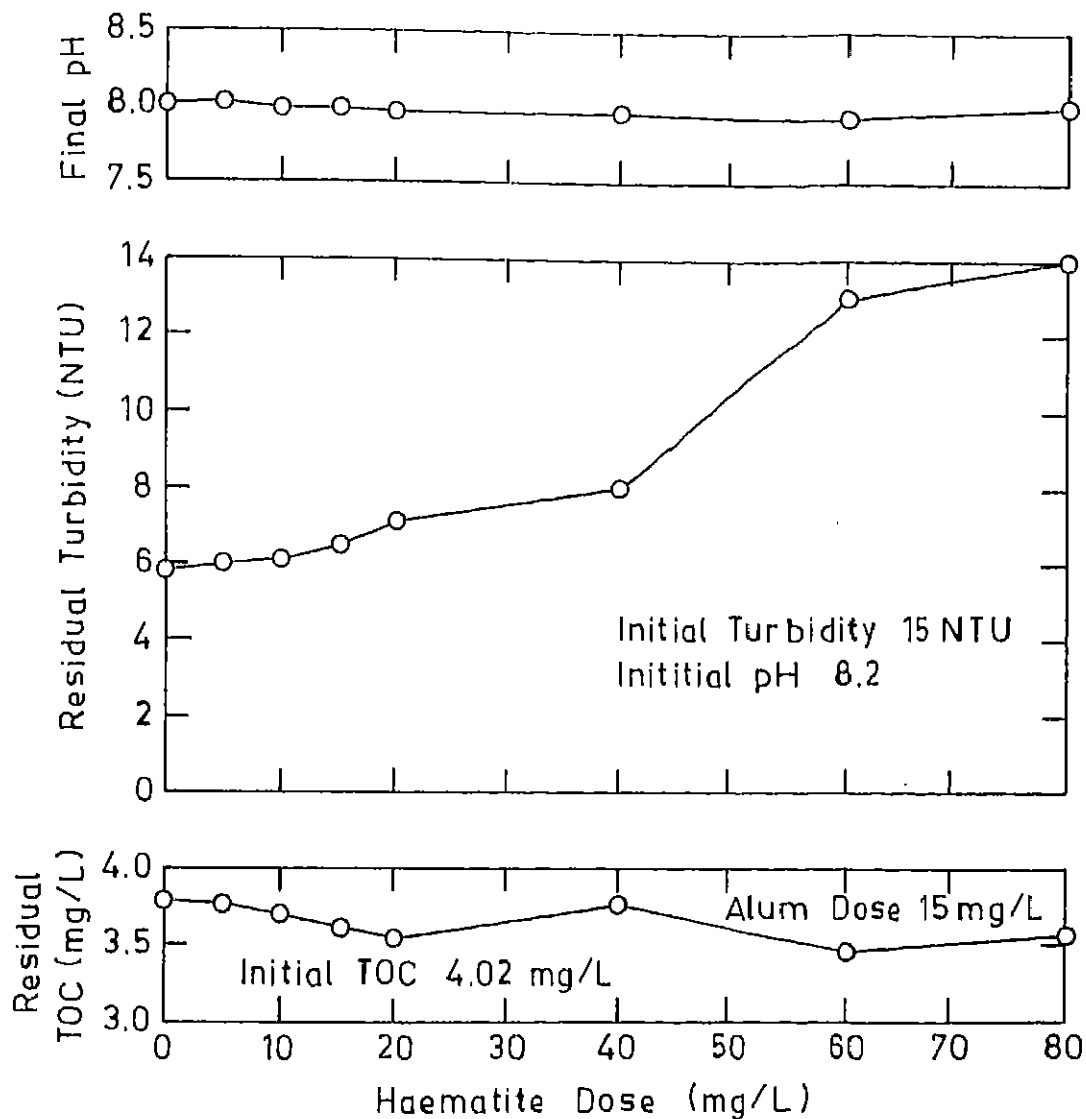


Fig. 7. Residual TOC and Turbidity Following Alum Coagulation with Haematite as Coagulant Aid.

Figure 8, only marginal improvement in residual TOC level was observed in some tests.

5.3.4 Two-Stage Coagulation

Two-stage coagulation experiments were conducted to assess whether organic matter removal could be improved by altering the way in which the alum was added. Sorption of dissolved organic matter on to metal hydroxide floc or incorporation of humic material (water-soluble or water-insoluble humic-metal complexes) within the metal hydroxide floc as mechanisms of organic matter removal by coagulation suggested that coagulation would be more effective for organic matter removal if the alum were applied in a two-stage process. In this way higher organic loading may be achieved on alum added to the first stage. In single stage coagulation organic loading on alum is always low since it is in equilibrium with low effluent TOC.

To provide a background for two-stage coagulation experiments, jar tests were conducted in December, 1987 with three raw water samples. The plant alum dose during this period was 12-13 mg/L. Based on the data presented in Figure 9, a 15 mg/L alum dose was selected for the two-stage coagulation experiments. From the data of three jar tests on single-stage and two-stage coagulation (Figure 10), it is apparent that marginal improvement in residual TOC level may be attained by two-stage coagulation. Semmens and Field(1980) in their study on single-stage and two-stage coagulation did not observe any beneficial effect of two-stage coagulation on TOC removal. It is to be noted that they adjusted the pH to 5.0 following rapid mix and hence,

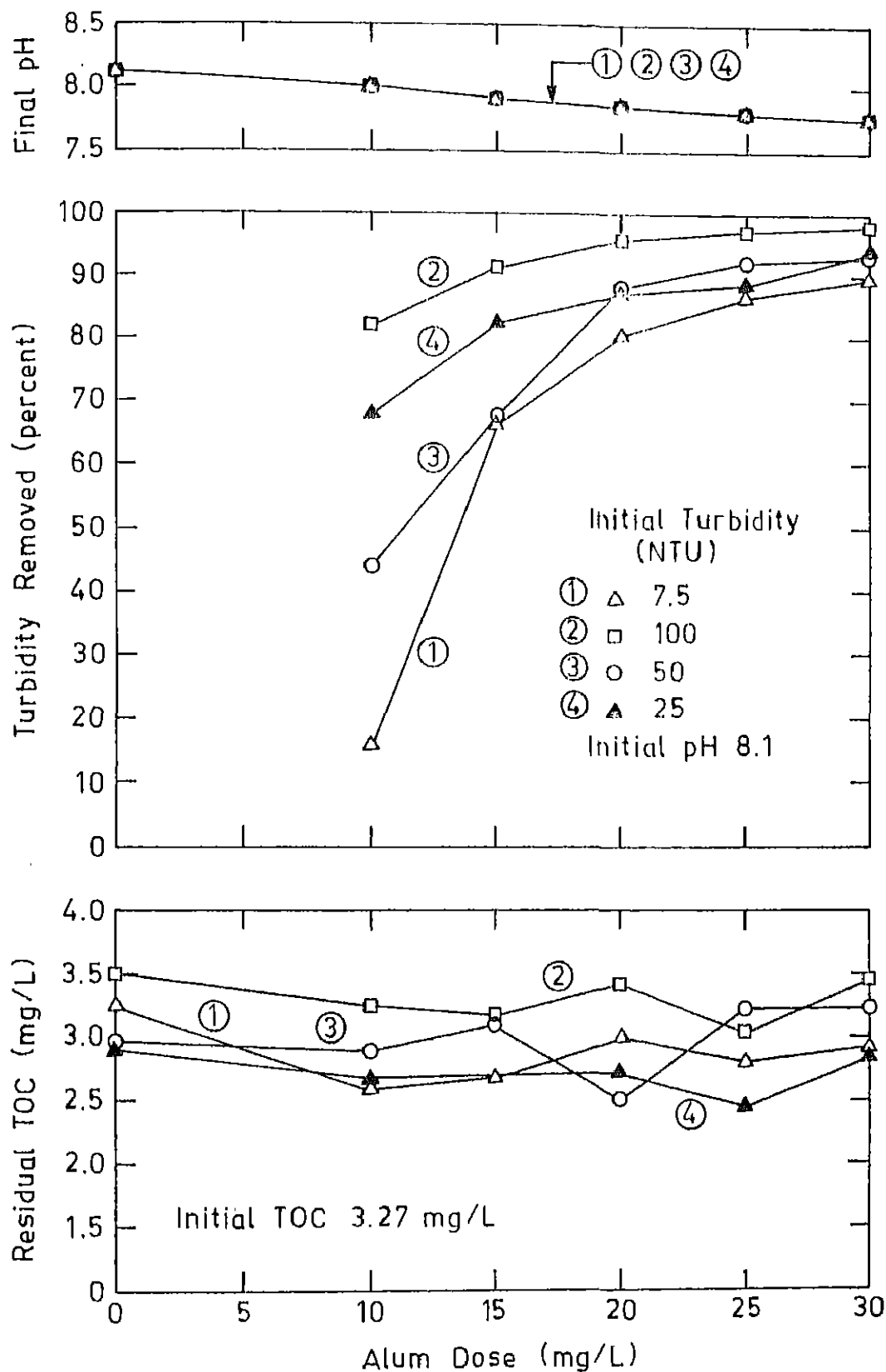


Fig. 8. Effect of Increased Initial Turbidity on Residual TOC and Turbidity Removal by Alum Coagulation.

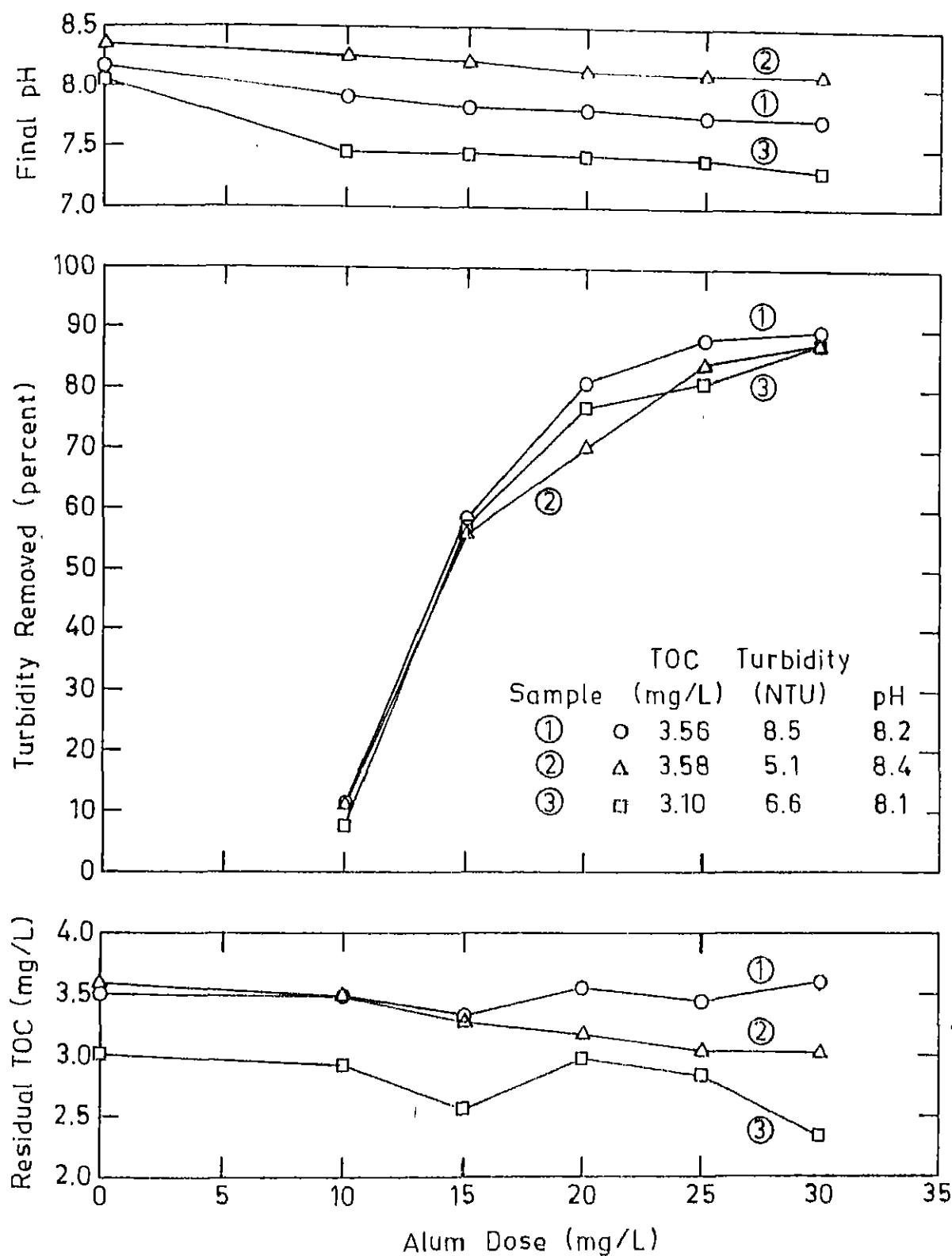


Fig. 9. Residual TOC and Turbidity Removal by Alum Coagulation for December, 1987 Water Samples.

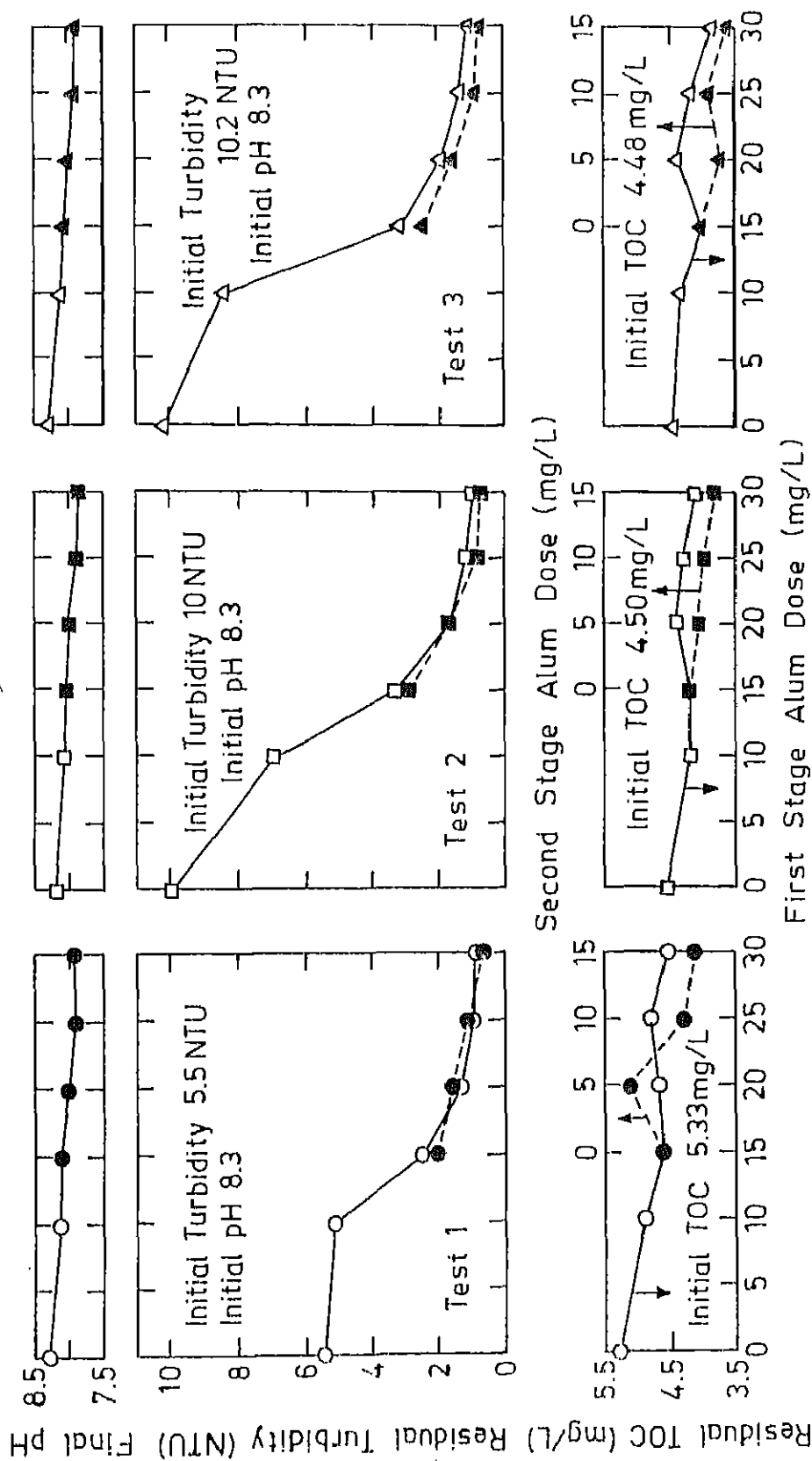


Fig. 10. Residual TOC and Turbidity Following Single and Two Stage Alum Coagulation (February, 1988).

at least for removal of humic substances, a different mechanism was effective viz., destabilization-charge neutralization.

5.4 Summary

Based on the laboratory coagulation studies on removal of organic carbon from water, some general observations may be summarized. No significant improvement in TOC removal may be attained by modifying the present alum coagulation practice in the Kanpur Water Works. However, increase in the plant alum dose (25-35 percent) may prove beneficial in lowering the TOC level of the water. Only marginal improvement in TOC level may be attained by increasing initial raw water turbidity. Further, two-stage alum coagulation may also provide marginal improvement in residual TOC level.

6. GENERAL SUMMARY

Organic carbon levels in the treatment trains at the Kanpur Water Works were estimated in the summer (June) and in the post-monsoon period (October) of 1987. Raw water (river Ganga) organic carbon levels were estimated during the entire study period (June, 1987-February, 1988). Raw water total organic carbon (TOC) level showed seasonal variation in the range 1.38-6.36 mg/L, the peak (5.91-6.36 mg/L) being during February-June. TOC levels in the treatment trains were significantly higher in summer (2.74-5.45 mg/L) compared to those in the postmonsoon period (1.45-2.51 mg/L). According to the published information on TOC levels for trihalomethane formation and water quality deterioration in the distribution system, both potentials exist in the Kanpur Water Works; however, water quality deterioration may occur only during certain parts of the year (February-June).

A laboratory study on removal of organic carbon from the Kanpur Water Works raw water (river Ganga) by alum coagulation was conducted to assess the effects of initial pH, alum dose and initial turbidity on TOC removal. Potential of using haematite as a coagulant aid in conjunction with alum as well as possible beneficial effect of two-stage alum coagulation were also investigated. The results of the study indicated that no significant improvement could be obtained by modifying the present coagulation practice in the Kanpur Water Works. However, increase in the plant alum dose (25-35 percent) may prove beneficial in lowering the TOC levels of water.

7. SUGGESTIONS FOR FUTURE WORK

Based on the observations and shortcomings of the present study, the following suggestions for future work may be made.

1. Weekly monitoring of organic carbon levels in the treatment trains for a period of one year.
2. Diurnal variation of organic carbon levels in the raw water and the treated water as well as at various sampling points in one treatment train so as to assess treatment efficiency in terms of organic carbon removal.
3. Correlation between trihalomethane formation potential (THMFP) and TOC levels of water.

In case of high THMFP, efforts should be made to streamline plant operation so as to reduce contribution of organic carbon. Also, other modifications of the coagulation process, e.g., powdered coal or activated carbon additive should be evaluated.

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